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PRECISION WEIGHT CALIBRATION WITH A SPECIALIZED ROBOT

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ABSTRACT

A selected commercial top-loading balance with a range of 200 grams and a resolution of 10 micrograms has been adapted for use in conjunction with a specially designed robot arm configured to load and unload the balance in accordance with established weighing designs. The complete system includes a personal computer for control of the robot and the balance, a 6-axis stepper motor controller, and a system for maintaining the balance, the robot, and the stored weights at a constant temperature.

INTRODUCTION

The calibration of weight sets in the range from 1 gram to 200 grams has until recently been performed manually at The National Bureau of Standards. Single- or double-arm swinging-pan type balances are generally the preferred instruments for this work on account of the high precision obtainable from them. Unfortunately, pan-type balances are more difficult to automate than top loading balances. When a weight is placed at some distance from the center of a pan, the gimbal system allows the pan to swing to a new angle, with the center of mass of the weight and pan directly below the gimbal. This shifts the position of the weight, and makes it difficult for the robot to locate it again. Since it is necessary to place several weights on a balance at the same time in order to accomodate the standard weighing designs that are used in the calibration process (1), it was concluded that a pan-type balance would not be a good choice for a first effort at automation.

When we were beginning to study the problems of automating the NBS weighing process, a special top-loading balance was obtained from The Mettler Instrument Co. (2), which was a 200 gram balance modified to provide a resolution of 10 micrograms and more carefully adjusted than a standard instrument. This instrument has a digital read-out, and includes a computer interface by means of which it can be read and controlled. A top-loading balance contains a cantilevered parallelogram construction which, when combined with its servo position control, constrains the pan to a fixed position. This feature simplifies the process of automatically loading and unloading the balance.

A disadvantage of top-loading balances is that the parallelogram, which is implemented with flexure-type pivots, cannot be perfectly adjusted, nor can it be perfectly rigid; consequently the balance reading depends to a significant extent upon the position of the weight on the pan. Although this is a serious problem with a manually operated balance, a robot is capable of loading the pan in such a way that the center of mass of the set of weights is always centered on the pan. These considerations led us to design our first automatic weight calibration system around a top-loading balance.

Standard calibration designs used with 5-2-2-1 and 5-3-2-1 weight sets require that up to seven weights be placed on a pan at one time. The system described here will accept no more than seven weights at a time, but could in principle be modified if more than seven were required.

ROBOT ARM DESIGN

The important requirements for a robot arm to be used for loading a balance are first, that it must not contaminate the weights with dust or other foreign matter; second, that it must not appreciably affect the temperature of the balance or the weights; and third, that it must have the capability of accurately determining the diameters of the weights under test, and of gently placing them on the balance pan. Although a standard clean-room robot would have satisfied the first requirement, we were unable to find a commercial robot that filled all of the above requirements without exceeding our budget, so we undertook the design of a special robot to serve our needs.

Stepper motors were chosen for use in the robot arm. A six-axis stepper motor controller (3) was constructed to drive the motors with programmable speeds and accelerations, and to provide the auxiliary function of opening and closing the balance door. A spare stepper motor channel is available for possible future expansion. The controller can also read up to 12 limit switches, and can be programmed to stop any of the motors according to the states of the switches. The controller is operated through an IEEE 488 bus interface.

A schematic view of the robot arm is shown in Figure 1 and described in the caption. The two rotary motion joints contain worm gear reduction drives which control the motion of the gripper assembly to a resolution of about 0.15 mm per step. The elevator case contains two ball-screw assemblies in line with the cantilevered elevator arm. They are geared together and driven from a motor in the motor case through a vertical shaft coaxial with the elevator case bearing.

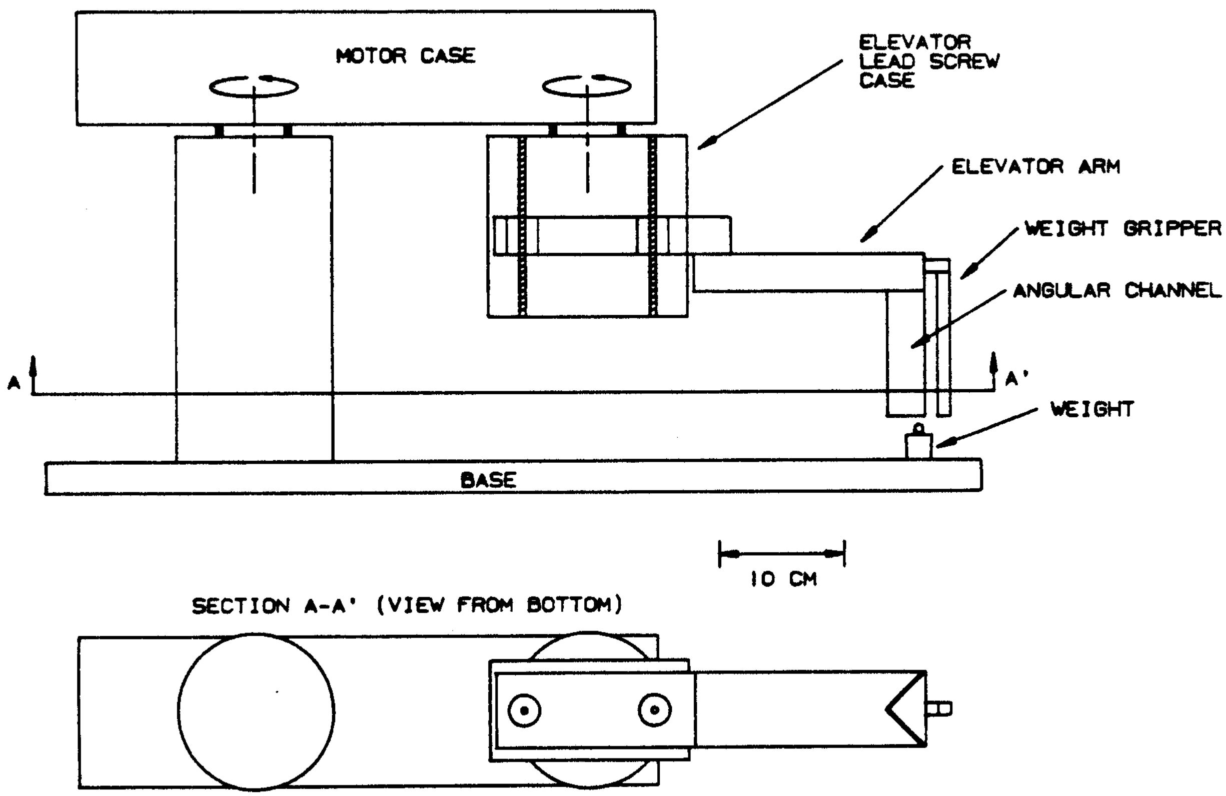

Figure 1. Three stepper motors are located inside the motor case. They cause the motor case to rotate, the elevator lead screw case to rotate, and the elevator arm to move up and down. A fourth stepper motor, which is a low-power linear actuator, is contained in the elevator arm. It causes the weight gripper to move towards the vertex of the angular channel at the end of the elevator arm, to grip or release the weight.

The swivel bearings between the arm support and the motor case, and between the motor case and elevator case, are double row extra-light-duty ball bearings with inner bores of 45 mm. All electrical connections between the base, the motor case, and the elevator case are made through coiled retractile cables that pass through these bearings. Covers are installed around the motor case and elevator case to trap and retain dirt and oil particles so they do not contaminate the weights. The weight gripper and the angular channel, between which the weights are grasped, are lined with strips of photographic-grade chamois that were further treated by soaking in acetone to remove excess oils.

The robot arm grips a cylindrical or slightly tapered weight gently but firmly at three points around the sides by squeezing it between the chamois-lined parts of the gripper assembly. The small linear actuator driving the gripper rod is allowed to stall when it contacts the weight. The stall force of the motor, in conjunction with the high friction coefficient of the chamois, provides ample retention of the weight. An optical limit switch is installed to indicate when the gripper is fully open. This makes it possible to determine the diameter of a weight by counting the number of steps taken in moving from the stalled position to the fully open position. This information is used by the balance program to place a weight at a specific position on the pan.

Optical limit switches are used to verify and correct the starting locations of each of the stepper motors when the balance program is started. If the switches are not initially in the correct states, the operator is called upon to correct the arm position using an auxiliary program.

GENERAL ASSEMBLY

The base of the assembly is a 25 mm thick aluminum plate. The balance is located on the base plate using a kinematic mount, and the weights are placed directly on the base in numbered locations marked by angular rulings on the aluminum. The angular location marks correspond to the positions assumed by the angular channel on the elevator arm when the arm is sent to the indicated position. The base is loaded with weights to be calibrated by placing each weight within a marked channel.

Surrounding the entire system of base, balance, and arm is a transparent dust cover with openings to provide for the circulation of air with the room. The room is not closely temperature controlled, but is an interior module shut off from the building air conditioning system. The aluminum base of the instrument is temperature regulated, which helps to control the temperature of the entire balance assembly. The base rests on a 25 mm thick slab of foamed polystyrene, which rests in turn on a marble pier. It is believed that the pier is not required for the proper operation of the system.

The electronics packages connected with the measurement system include the stepper motor driver, the balance servo and control package that was removed from the balance and relocated to reduce the temperature rise of the system, and a voltmeter and multiplexer system for monitoring the temperature, pressure, and relative humidity of the air within the balance. All of these instruments are controlled through the IEEE 488 bus interface of a portable personal computer. The electronics package is located about two meters from the balance, and is well above it.

PROGRAMMING

The program that runs the balance assembly consists mostly of FORTRAN code, with the addition of a few assembly language subroutines intended to provide better control of the monitor and keyboard of the personal computer, and to implement a special control-break handler to stop the arm immediately if the occasion requires. The entire object code package has a length of about 114,000 bytes.

The task of the balance operator is to clean the weights requiring calibration, and to place each weight at one of the numbered positions on the aluminum base plate. The weights must be placed in accordance with a weighing schedule, which is an ASCII file listing the weights to be included in each reading, and indicating such auxiliary information as the balance settling time, the temperature, pressure, and humidity measurement sequence, and the number of times to repeat the schedule. The operator selects an existing weighing schedule, or may create a new one using a standard text editor, and starts the program. The program places the measurement results in an ASCII file that contains such additional information as the time of each measurement, and the file name of the weighing schedule. This output file may then be used as the input file of a data analysis program.

MEASUREMENT RESULTS

Beginning in September, 1987, the mass calibration group at NBS began calibrating the 1-gram to 100-gram weight sets that are received for certification using the new automatic system, as well as with the standard manual technique. The balance used with the manual system was a pan-type instrument which provides a better precision then can be obtainable with the top-loading balance which is presently used with the automatic weight changer. A final analysis of the results is not yet available, but the manual system definitely provides smaller uncertainties in a given length of time. It is anticipated that the automatic system will be able to yield uncertainties comparable with those obtained manually through its ability to average the results of a number of measurements.

REFERENCES

(1) Cameron, J.M.; Croarkin, M.C.; Raybold, R.C. "Designs for the Calibration of Standards of Mass," NBS Tech Note 952; June 1977.

(2) This particular balance was used because it was available at the required time. We do not endorse this or any other product. It is not necessarily the most applicable for the job.

(3) Cutkosky, Robert D.. "A Six-Channel Stepper Motor Controller for Use in Laboratory Instruments," (To be published).